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MONOLITHIC GaAs DUAL-GATE FET PHASE SHIFTER

RCA Laboratories
Princeton, New Jersey 08540

JANUARY 1981

TRI-ANNUAL REPORT NO. 1
for the period 1 September 1980 to 31 December 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the progress made, during the period 1 Sept. 1980 to 31 Dec. 1980, in the development of a monolithic GaAs dual-gate FET phase shifter. The development of a 0 to 360° phase shifter using discrete components is described. The results on the variation of phase shift with bias voltages of the dual-gate FETs are presented over 4- to 8-GHz band. The progress made in the development of monolithic 0 to 90° phase shifter is also presented.	

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PREFACE

This Tri-annual reports the work perfomred under Contract No. N00014-79-C-0568 1 September 1980 to 31 December 1980 in the Microwave Technology Center, F. Sterzer, Director. H. C. Huang is the project supervisor and M. Kumar is the project scientist.

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I. Objective

The objective of this four-year program (Sept. 1, 1979 to Aug. 31, 1983) is to develop a monolithic GaAs dual-gate FET phase shifter, operating over the 4- to 8-GHz frequency band and capable of a continuous programmable phase shift from 0° through N times 360° where N is an integer. The phase shift is to be controllable to within ±3°. This phase shifter will be capable of delivering an output power up to 0 dBm with an input and output VSWR of less than 1.5:1.

II. Progress

This program started on September 1, 1979, with a long-term goal of developing a 360° monolithic dual-gate FET phase shifter. The first phase ended on August 31, 1980, and now this program has been extended for three additional years ending August 31, 1983. The first-year goals of this program were to demonstrate a 0 to 90° phase shifter using discrete dual-gate FETs on microstrip circuitry and to start developing the monolithic components of the phase shifter. During this year, we first demonstrated a 90° phase shifter and then demonstrated a 360° phase shifter using discrete components on microstrip circuitry. The 360° phase shifter was demonstrated on a breadboard model using a commercial 180° hybrid. We have also developed a monolithic dual-gate FET amplifier. Preliminary results showed a 3- to 5-dB gain over the band. We are in the process of improving the design of the monolithic dual-gate FET amplifier where we will ground the sources of the FET using via hole techniques. We are also developing a 90° hybrid and Si_3N_4 MOM capacitor on a GaAs semi-insulating substrate. This capacitor will be used as a blocking capacitor as well as an rf bypass in the bias circuit.

The goals for the second phase of this program (Sept. 1, 1980 to Feb. 28, 1982) are to develop and demonstrate a 0 to 90° monolithic phase shifter. This will involve the development of a monolithic dual-gate FET amplifier, a 90° hybrid and a two-way, in-phase combiner. Development of a 180° hybrid, characterization of lumped elements, and a four-way in-phase combiner will also be started in this phase and will continue through the next phase of the program.

The goal of the third phase of this program is to integrate all the components developed previously to achieve a monolithic, 0 to 360° phase shifter over the 4- to 8-GHz band.

A. Development of Discrete 360° Phase Shifter

In this Tri-annual report period, Sept. 1, 1980 to Dec. 31, 1980, we have fabricated a discrete 360° phase shifter, begun the design and development of monolithic circuit components such as couplers and capacitors on GaAs, and have continued the effort in ion implantation into GaAs SI substrates.

The schematic of a 360° phase shifter is shown in Fig. 1. The photograph of the newly developed, discrete, 360° phase shifter is shown in Fig. 2. The variation of phase shift with control voltages (the second gate bias voltages, V_{G2}s) is presented in Figs. 3 through 7 at 4.5, 5, 6, 7, and 7.5 GHz. The 0 to 360° continuous phase shift is obtained by changing the second gate bias voltages of the dual-gate FET amplifiers in a systematic manner. This can be further explained with an illustration. Referring to Fig. 3, there are four sections which divide the total phase shift of 360° by four dotted vertical lines. Each section represents the phase control of one quadrant. In each section the bias voltages of the second gate of dual-gate FET amplifiers is varied for two amplifiers, e.g., A and B, B and C, C and D, or D and A, while the remaining two amplifiers are switched off by applying -4 V to their second gates. In the first section, the V_{G2}s for A and B are varied while V_{G2}s for C and D are kept at -4 V for switch-off condition. Now to get a 90° phase shift, first amplifier B is in the on condition [V_{G2} (B) = 0 V] and the V_{G2} (A) for amplifier A is varied from -4 V to 0 V, which gives approximately the 45° phase shift. Next, amplifier A is switched on [V_{G2} (A) = 0 V] and the V_{G2} (B) for amplifier B is varied from 0 to -4 V which gives approximately from 45° to 90° phase shift. Thus, controlling the two second-gate bias voltages of two amplifiers, a 90° phase shift is obtained. This process is repeated with other combinations to obtain the entire 360° phase shift.

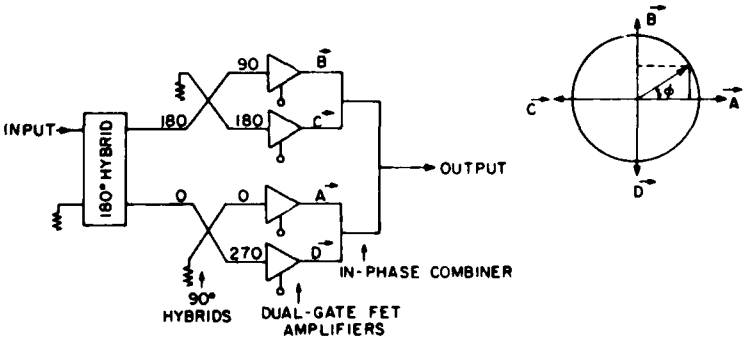

Figure 1. Schematic diagram of a 0 to 360° GaAs dual-gate FET phase shifter.

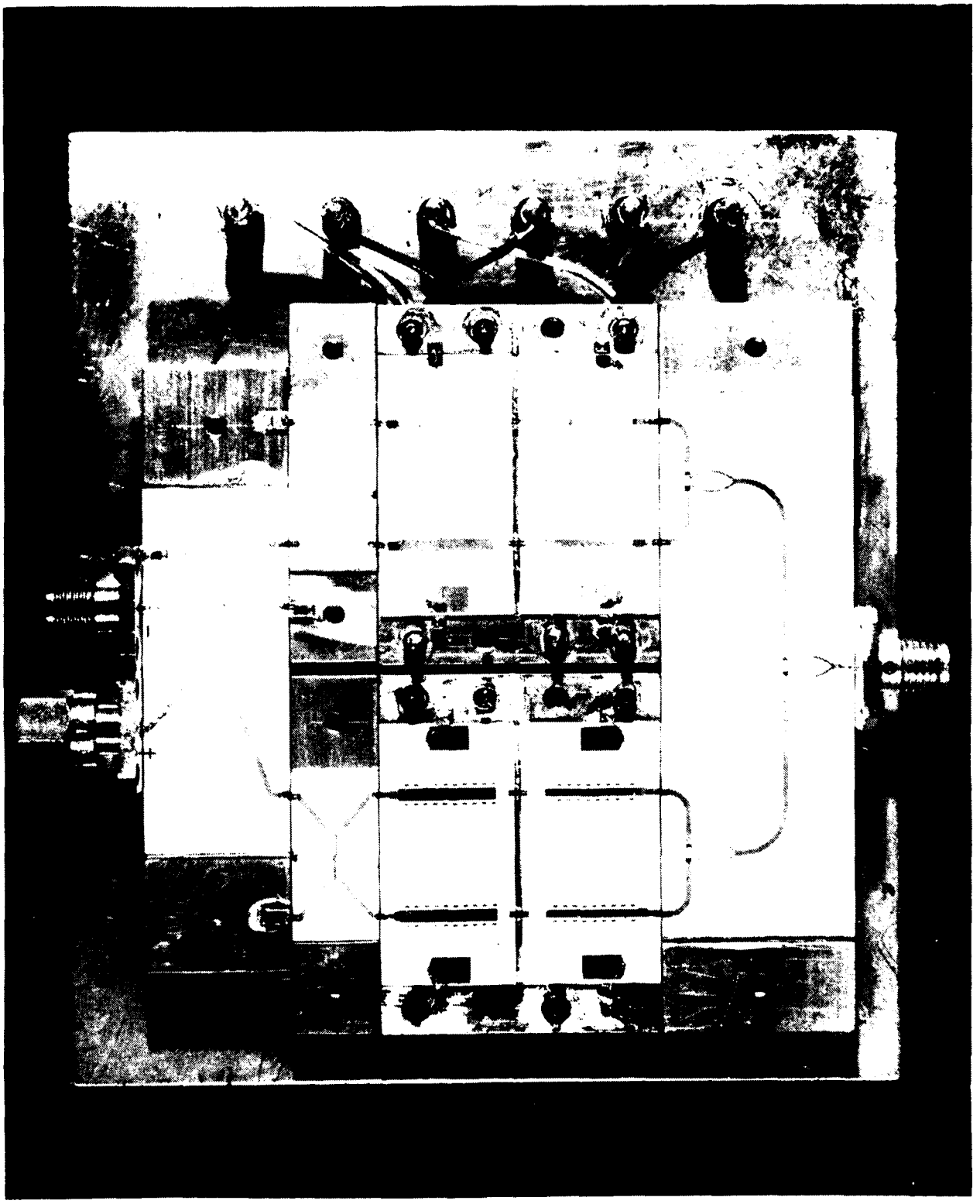

Figure 2. Photograph of the 0 to 360° GaAs dual-gate FET phase shifter.

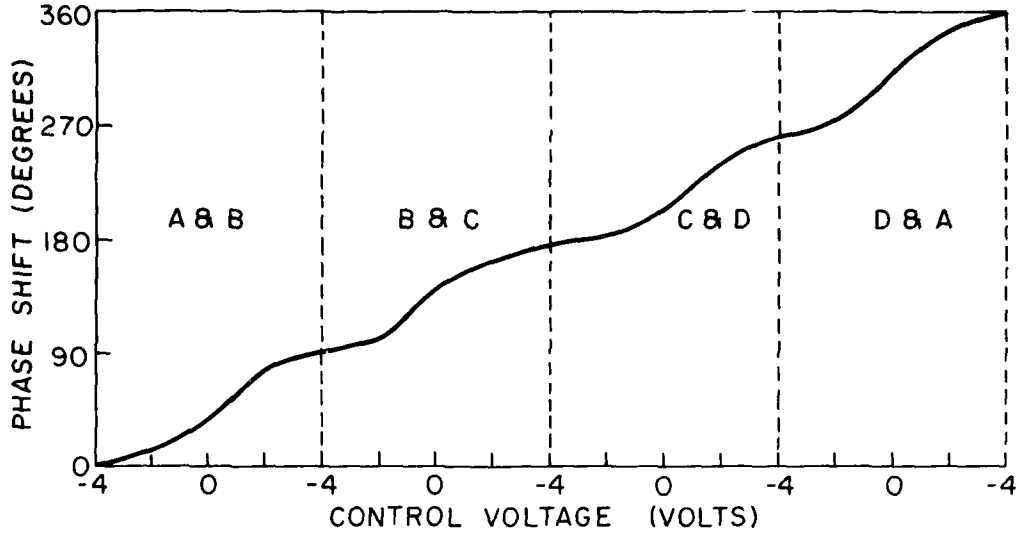

Figure 3. Variation of phase shift with control voltages (V_{G2}) of 360° phase shifter at 4.5 GHz.

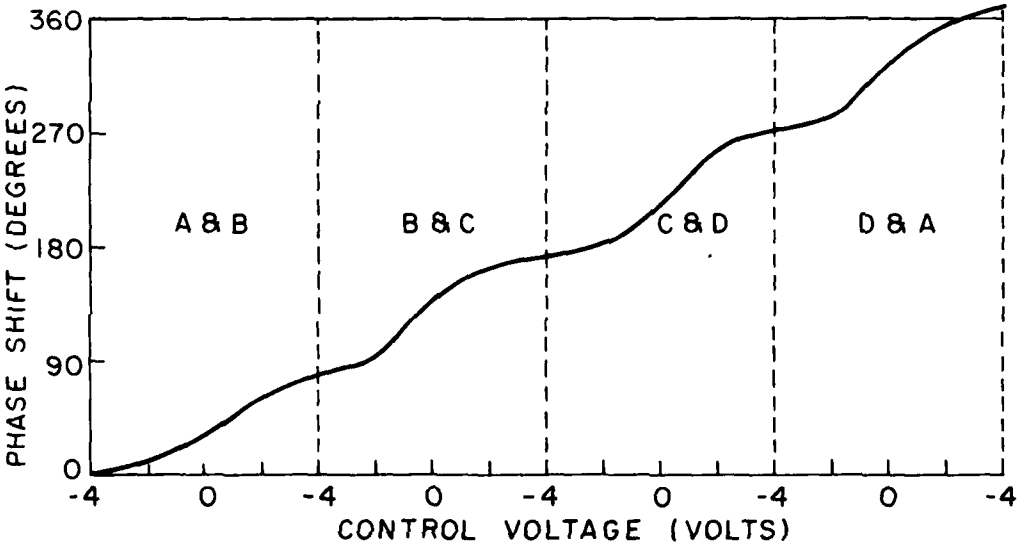

Figure 4. Variation of phase shift with control voltages (V_{G2}) of 360° phase shifter at 5 GHz.

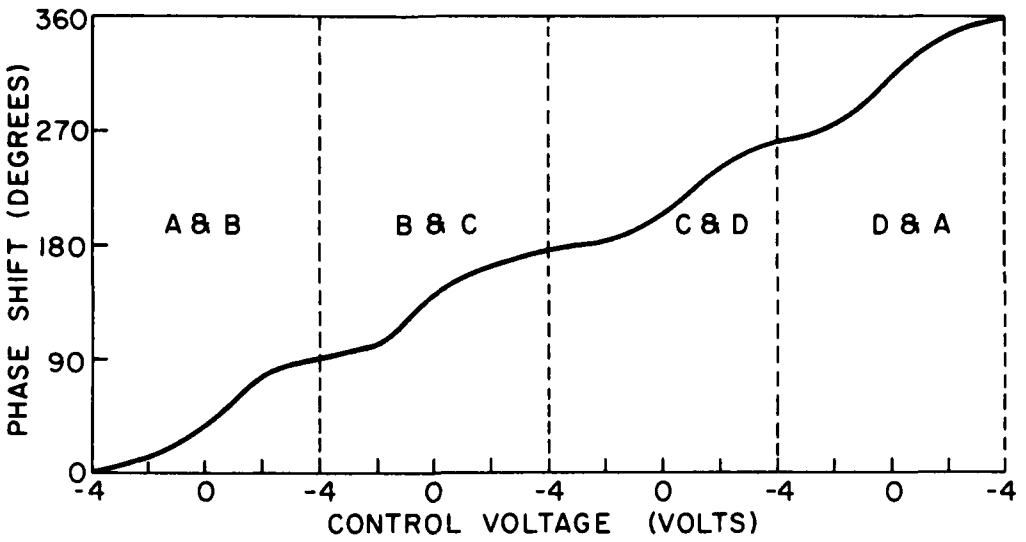

Figure 5. Variation of phase shift with control voltages (V_{G2}) of 360° phase shifter at 6 GHz.

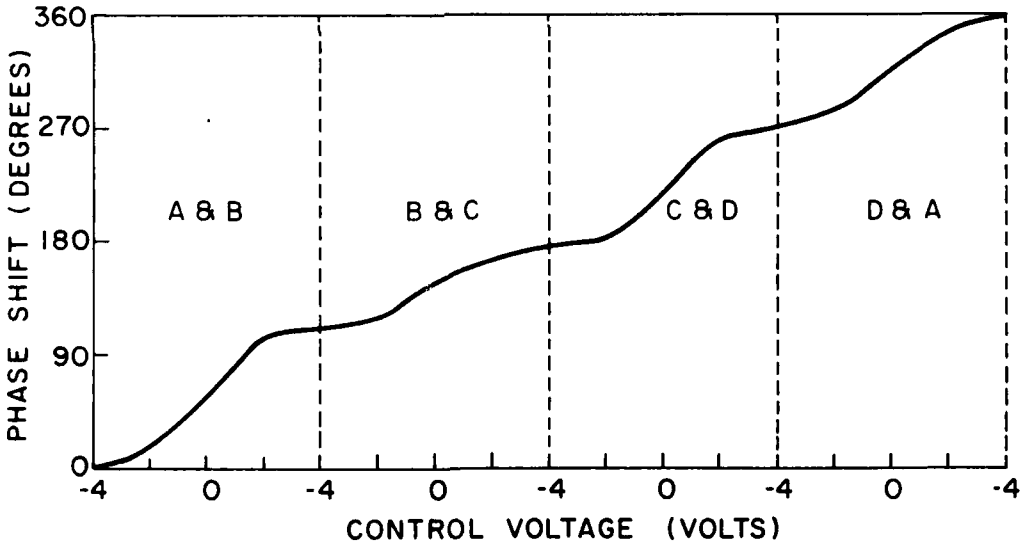

Figure 6. Variation of phase shift with control voltages (V_{G2}) of 360° phase shifter at 7 GHz.

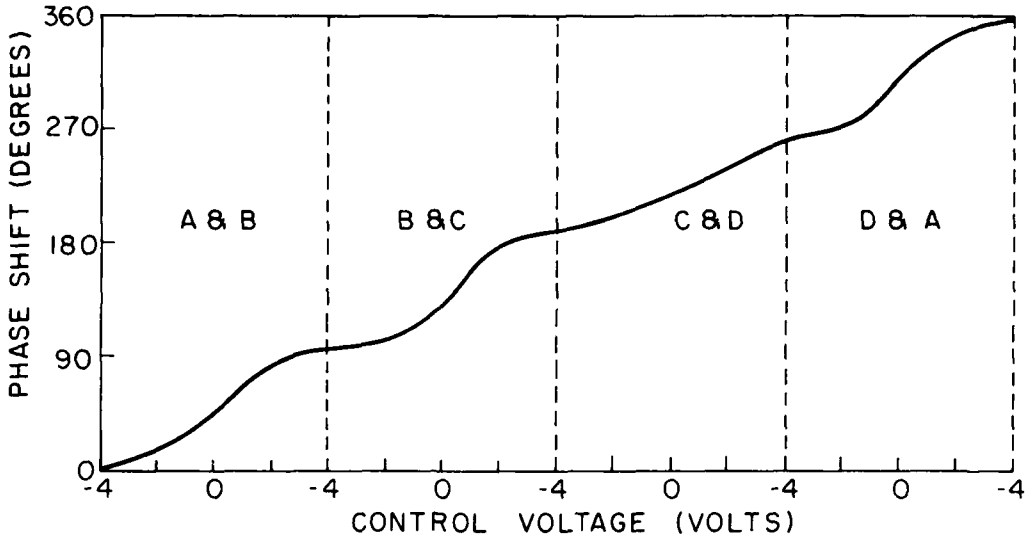

Figure 7. Variation of phase shift with control voltages (V_{G2}) of 360° phase shifter at 7.5 GHz.

In Figs. 3 through 7 it is seen that the phase is not a linear function of the control voltage. This is because the variation in gain of a dual-gate FET amplifier with the second-gate bias voltage is not linear. However, the control voltages can be programmed with the help of a microprocessor to obtain the linear phase shift. This is conceptually illustrated in Fig. 8 at 6 GHz. We are currently investigating the feasibility of modifying the dual-gate FET design to improve the phase linearity.

B. Development of Monolithic 90° Phase Shifter

In this reporting period we have started the mask design for a complete monolithic 90° phase shifter. A 90° phase shifter consists of the following components: one 90° hybrid, two dual-gate FET amplifiers, and an in-phase power combiner. The mask design for the complete monolithic 90° phase shifter is in progress. To evaluate the performance of each component, we are also developing individual 90° hybrid, dual-gate FET amplifiers and in-phase power combiners on semi-insulating substrates. We have designed a 4-line, 90° interdigitated hybrid for 50-ohm input and output impedances. The mask has been procured and the fabrication of this hybrid is underway. This hybrid is designed for 100-μm-thick GaAs substrates. The finger width of the hybrid is 7 μm and the finger spacing is 6.5 μm. The length of the hybrid is 4390 μm (172.8 mils).

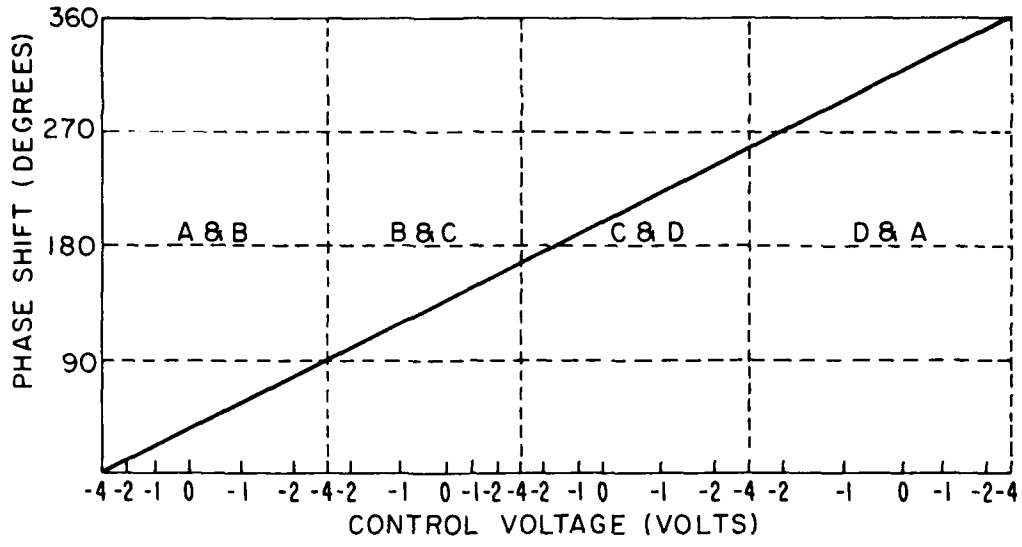

Figure 8. Linear phase shift with control voltages (V_{G2}) of 360° phase shifter at 6 GHz.

We have also designed a 6-line, 90° interdigitated hybrid for 25-ohm input and output impedances. The finger width and spacing for this hybrid are 19 μm and 11 μm, respectively. The substrate thickness is 100 μm. The total area of this coupler is approximately the same as that of the 4-line coupler. The major advantage of a 25-ohm, 6-line coupler is in reducing the area required for matching circuits of the dual-gate FET amplifier. A dual-gate FET has input and output impedances of the order of 10 to 20 ohms. Thus, using a 25-ohm coupler as compared to a 50-ohm coupler will require less matching elements for the dual-gate FET. To provide a transition between the 25-ohm system to the conventional 50-ohm system, we have also designed a wideband, 25- to 50-ohm transition using $\lambda/16$ transformers. We are in the process of designing an in-phase power combiner for the 90° phase shifter. Here, again, we designed the power combiners with 50-ohm output impedance and 25-ohm input impedance, respectively. Masks for the 50-ohm, 4-line hybrid and 25-ohm, 6-line hybrid have been procured and the fabrication is in progress.

We reported the results of a monolithic dual-gate FET amplifier in Bi-monthly Report No. 3. The mask of the monolithic dual-gate FET amplifier is being modified to incorporate the via holes for grounding the sources, air bridge between two second gate pads, and the dc bias circuit on the chip.

We have fabricated a number of Si_3N_4 MOM overlay capacitors on SI GaAs with capacitance values in the 10- to 20-pF range. The breakdown voltage for these capacitors is in the range of 50 to 80 V, which is more than adequate for our application. The rf characterization of these capacitors is in progress. We also fabricated a number of lumped elements, e.g., single-loop and spiral inductors and interdigital capacitors, which are used for matching the input and output impedances of the FET. The rf characterization of these elements is also in progress. We are using the resonant and transmission methods for their characterization.

The resonant method is suitable for small values of lumped elements, and the transmission method is suitable for the large values of lumped elements. The test fixtures for these measurements have been fabricated and we are in the process of rf characterization.

We have received some commercial GaAs SI substrates which were ordered during the last quarter. We are in the process of qualifying those substrates for ion implantation. In addition, we have ordered and received some vapor epitaxially grown, n^+-n-buffer-SI substrate wafers from Microwave Semiconductor Corporation (Somerset, NJ).

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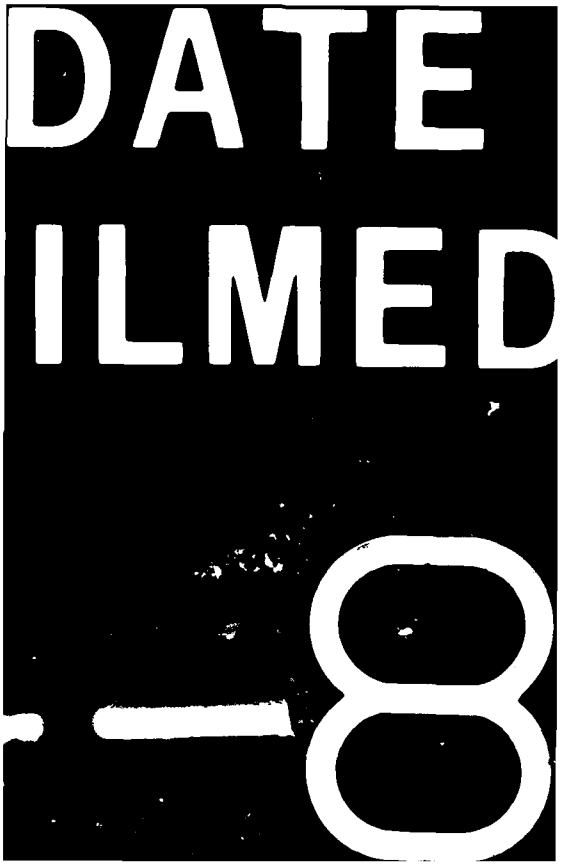
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